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Abstract: This article presents a microeconometric analysis of the annual mileage travelled by French households with their personal cars, defining their automobility. To feature car use dependence, the rational addiction model of Becker et al. (1994) is applied on a panel dataset, drawn from the French "Car Fleet" survey over the period 1999-2001. Importantly, the estimates show that the assumption of addiction to car use cannot be rejected. Furthermore, the model yields realistic kilometric-price and income elasticities of household automobility, for both the short and the long runs.

Keywords: Transportation, Car use, Consumption, Addiction, Panel, GMM.

JEL Classification: C23, D12.

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1.0 Introduction

Contribution of mankind activity to climate change and the related ecological issues are subject to tempestuous political and scientific discussions. Whoever may be right about the exact assessment of causes and consequences, French policy makers have decided to set more and more ambitious environmental targets, and measures are implemented to converge towards a more sustainable development. Voted in 2005 by the French Parliament, the energy law aims at dividing by 4 the 1990 level of greenhouse gases at the horizon 2050. In a more global perspective, we refer the reader to the debated results since the 1979 world climate conference in Geneva up to the 2009 climate change conference in Copenhagen. Nowadays, there is a large international consensus about the emergency to make the economic growth cleaner. However, it is noteworthy that there is no general agreement about the way to manage it.

Transportation is a sector for which a particular effort is deemed essential. Industrial strategies and policies concern both supply and demand sides. As it regards the latter, the subtopic of travel demand focuses on behavioural changes and incentives to turn towards more sustainable means of travelling. A special attention is paid to emission of greenhouse and other toxic gases but not only. Indeed, the perspective of global peak oil and oil scarcity pleads for the necessity to find new and/or more efficient ways to travel, as it should entail an increase of fuel prices in a near future. Therefore, the question of car use intensity emerges, given that current technology is mainly based on fossil resources. In a context of highly volatile and increasing fuel prices, it is of great importance to understand and to quantify to what extent households adapt their behaviours in terms of car ownership and use. Although not that much new, this remains a major topic of research.

Car provides users with a larger control of space and time, and allows a better access to jobs, leisure places, health care, public amenities... On the other hand, car users may develop a kind of dependence, as pointed out by Dupuy (1999, p.1):

> *"… automobile dependence means that as individuals, we cannot live without cars, just as a smoker cannot live without cigarettes, and a drug addict without drugs."*

Below, Wickham (2002, p.16) also compare car use with an addictive consumption of drugs. Our microeconomic reading is proposed in parentheses.

> *"Car* (use) *dependence can be understood through the metaphor of drug dependency* (addiction)*. Heroin or even nicotine addiction is in part a matter of* (rational) *choice. I choose to shoot up, I choose to smoke a cigarette. But as I continue to do this, my body* (utility function) *changes, it becomes restructured, it needs the drug* (addictive good), *it cannot do without it. Furthermore, the need (addictive good marginal utility) escalates the body* (optimal bundle of goods) *requires more and more of the drug* (addictive goods)*... the same applies to car* (use) *dependency."*

In the present article, we propose a microeconometric analysis of the annual mileage travelled by French households with their personal cars. In the literature, this mileage is sometimes referred to as household “automobility”, and we will use indifferently both expressions all along the paper. A two-step structure is applied: after considering the dichotomous choice of households to own cars or not, their automobility is modelled. An objective focuses on measuring price and income elasticities of car use. Moreover, the panel layout of the data, based on three annual waves (1999-2001) of the French “Car Fleet” survey, enables to use dynamic specifications and to derive short and long-run effects.

To feature the dependence of households to car use, the myopic and rational addiction models (Becker et al., 1994) are investigated. By applying these models, generally used to describe the consumption of cigarettes, alcohol or drugs, the previous authors’ assertions can be tested from the microeconomic point of view. To our knowledge, this article provides the first application of the rational addiction model to describe car use behaviour, while “automobile dependence” is a major topic of research in transportation.

The rest of the article is fashioned as follows. Section 2 presents the theoretical framework: the rational addiction model and its properties are examined. Section 3 discusses the econometric specification and the estimation method. Section 4 provides a description of the 1999-2001 French “Car Fleet” panel dataset. Section 5 reports and debates the estimation results. Conclusions are drawn in a last section and further research tracks are also suggested.

2.0 Microeconomic framework

2.1 The rational addiction model

2.1.1 Description

Since Becker and Murphy (1988), a consumer is said to be addict to a good if, all the same, an increase in his past consumption yields a significant rise in his current consumption. Becker et al. (1994) developed an addiction model in which the individual current utility level U_t depends on the consumed quantity of two goods: a quantity X_t of a composite good X, and a quantity C_t of an addictive good C. The current utility also depends on a set of individual characteristics e_t related to lifecycle and potentially unobserved. The addictive and composite goods are different in that U_t also depends on the past consumed quantities of C. Following the authors, these quantities are accumulated into an addictive capital stock S_t, which is supplied at each current period by the past level of consumption C_{t-1}. Thus, the current utility of a consumer also depends on this stock. The most commonly used expression to define it simply writes: $S_t = C_{t-1}$.

The consumer looks to maximize his discounted utility over an infinite lifetime horizon:

$$Max \sum_{t=1}^{\infty} B^{t-1} U_t \left(C_t, C_{t-1}, X_t, e_t \right), \tag{1}$$

where $B=(1+\rho)^{-1}$ is the discount factor, ρ being the inter-temporal rate of substitution. Besides, it is assumed in the model that the composite X is the money and the interest rate of the economy is equal to ρ. Maximization of the consumer's utility is subject to an initial condition regarding the addictive good, and it is constrained by the inter-temporal budget equilibrium:

$$C_0 = C^0 \ ; \ A_0 = \sum_{t=1}^{\infty} B^{t-1}\left(X_t + P_t C_t\right), \tag{2}$$

where A_0 is the net present value of the consumer's wealth, P_t is the nominal price of the addictive good at date t. Let the utility function be concave and quadratic in the arguments C_t, C_{t-1}, X_t, e_t, and such as:

$$\begin{aligned} U_t\left(C_t, C_{t-1}, X_t, e_t\right) &= \alpha_C C_t + \alpha_S C_{t-1} + \alpha_X X_t + \alpha_e e_t + \frac{\alpha_{CC}}{2} C_t^2 + \frac{\alpha_{SS}}{2} C_{t-1}^2 \\ &+ \frac{\alpha_{XX}}{2} X_t^2 + \frac{\alpha_{ee}}{2} e_t^2 + \alpha_{CS} C_t C_{t-1} + \alpha_{CX} C_t X_t + \alpha_{Ce} C_t e_t + \alpha_{Xe} X_t e_t. \end{aligned} \tag{3}$$

Under the previous hypotheses, the optimal demand function for the addictive good is derived by solving the maximization program of the consumer. It is a function of its nearest past and future consumptions, the current nominal price P_t, and the characteristics e_t of the consumer:

$$C_t = \theta C_{t-1} + \theta B C_{t+1} + \theta_1 P_t + \theta_2 e_t \, , \tag{4}$$

where:

$$\theta = -\left(\left(\alpha_{CC}\alpha_{XX} - \alpha_{CX}^2\right) + B\left(\alpha_{SS}\alpha_{XX}\right)\right)^{-1}\left(\alpha_{XX}\alpha_{CS}\right). \tag{5}$$

For α_{CS} strictly positive, the past and current consumptions of C are said to be complementary. In this case, the current marginal utility of the addictive good, say U'_{C_t}, is an increasing function of C_{t-1}:

$$U'_{C_t} = \frac{dU_t}{dC_t} = \alpha_C + \alpha_{CC} C_t + \alpha_{CS} C_{t-1} + \alpha_{CX} X_t + \alpha_{Ce} e_t \, . \tag{6}$$

The higher the level of C_{t-1} and the value of α_{CS}, the higher the marginal utility of the addictive good. By analogy with "learning by doing", the consumer enjoys all the more the consumption of the addictive good as he "practiced" it in the past, and as the "learning speed" (α_{CS}) is high.

The temporal complementarity of the consumptions of C is the origin of addiction. It implies $\theta > 0$ in (5). The larger the estimated value of θ, the greater the level of addiction. The static and autoregressive consumption models are particular cases of the dynamic demand function (4). For $\theta = 0$, the demand function does neither depend on the past nor on the future levels of consumption and the static case emerges. When $\theta > 0$ and $B = 1/(1+\rho)$ drops to 0 (that is, for an infinite preference for the present), the demand function (4) takes the form of a first-order autoregressive process. There, the individual is not a forward looking agent. Becker et al. (1994) defines such a behaviour as myopic addiction. In any other situation where θ and B are strictly positives, the addiction behaviour is said to be rational. As both these parameters can be estimated, it is possible to test the most relevant formulation from the empirical perspective.

2.1.2 Testing for rational addiction

Testing the rational addiction theory has been performed on various data that pertain to different topics of research. Many applications dealt with drug consumption to tackle public health issues. For instance, Baltagi and Griffin (2001), Becker et al. (1994), Gardes and Starzec (2002), and Tiezzi (2004) used addiction models to explain the consumption of tobacco. Grossman et al. (1998), Bentzen et al. (1999), Baltagi and Griffin (2002), and Lalla et al. (2004) applied them to model the demand for alcohol. Van Ours (1995), and Grossman and Chaloupka (1998) tested the relevance of addiction models to explain the consumption of opium and cocaine.

As mentioned by Becker and Murphy (1988), there is no need to express a biological dependence to be considered as addicted to a good. There are other topics of application than drug consumption. For instance, Mobilia (1993) tested for addiction to gambling, Cawley (1999) focused on the consumption of calories, Villani (1992) dealt with addiction to art, Cameron (1999), and Sisto and Zanola (2005) applied addiction models to the demand for cinema. To our knowledge, the rational addiction model has not been applied yet to describe car use, while “automobile dependence” is a major topic of transportation research.

One needs however to be careful about the results of such models. Actually, whereas the effects of past and future consumptions on the current one are often found to be significant, the resulting inter-temporal rates of substitution are sometimes not convincing. Becker et al (1994) reported some rates ranging from 56 up to 223 per cent. Tiezzi (2004) also found unlikely values. Baltagi and Griffin (2002), Grossman et al. (1998), even reported some negative rates. All in all, a rule of thumb would be to accept the assumption of rational addiction on the basis of a “reasonable” rate[1] in addition to the statistical significance of past and future consumptions.

2.1.3 Measures in the rational addiction model

Although the core specification to test for the addiction hypothesis remains the model (4), it is often generalized to incorporate additional variables[2]. In the present approach, we consider that the current covariates are of two types: economic-related variables E_{it} (nominal price and income for example) and else-related variables S_{it} (socio-demographic and geographic variables for example). From the modeller’s point of view, E_{it} and S_{it} may both include

[1] Remember the assumption in the rational addiction model that the inter-temporal rate of substitution is equal to the interest rate of the economy. Arbitrarily, one can consider that a plausible rate should range between 0% and 20%. For instance, Becker (1996, p.103) reported a rate of 15%, arguing it is a “quite reasonable” value.

[2] As income, used in Becker et al. (1994) or Baltagi and Griffin (2002) for example.

observed and unobserved factors. These latter are all summarized by an error term ε_{it}. Let our specification be:

$$C_{it} = \theta C_{it-1} + \theta B C_{it+1} + S_{it}\alpha_0 + E_{it}\alpha_1 + \varepsilon_{it}, \tag{7}$$

where the subscripts *i* and *t* identify the individual and the period. The impacts on the current consumption resulting from a variation in the past and future consumptions can be deduced from the characteristic roots of the homogeneous equation of (7). They write:

$$\varphi_1 = \frac{1-\sqrt{1-4\theta^2 B}}{2\theta}, \ \varphi_2 = \frac{1+\sqrt{1-4\theta^2 B}}{2\theta}. \tag{8}$$

In (8), φ_1 and φ_2^{-1} measure the effect on C_{it} induced by a shock on C_{it+1} and C_{it-1} respectively. The elasticities in the rational addiction model can be expressed as functions of these characteristic roots. Let E_k be the k^{rd} continuous variable of E. The short and long-run elasticities of the demand for C with respect to E_k, valuated at the sample averages $\bar{E}_k$ and $\bar{C}$, and respectively denoted $e_{C/Ek}^{CT}$ and $e_{C/Ek}^{LT}$ are given by (Becker, 1996, p.113):

$$e_{C/Ek}^{CT} = \frac{\alpha_{1k}}{\left(\theta\left(1-\varphi_1\right)\varphi_2\right)} \times \frac{\bar{E}_k}{\bar{C}}, \tag{9}$$

$$e_{C/Ek}^{LT} = \frac{-\alpha_{1k}}{\left(\theta\left(1-\varphi_1\right)\left(1-\varphi_2\right)\right)} \times \frac{\bar{E}_k}{\bar{C}}. \tag{10}$$

Logically, the elasticities that stem from the myopic model are particular cases of (9) and (10) for $\varphi_1 = 0$ and $\varphi_2^{-1} = \theta$.

3.0 Modelling and estimation difficulties

3.1 Notations

Unless explicitly stated, the following notations will be used all throughout the rest of the paper. In addition to the subscripts *i* and *t* which identify respectively the household and the period, we consider also a subscript *v* which is related to a specific car owned by *i* at date *t*. These three subscripts are used all together to index the following variables:

- *KM*: the annual mileage converted into kilometres;
- *FE*: the average fuel efficiency in litres per 100 kilometres;
- *DP*: the price per litre of diesel oil in Euros;
- *PP*: the price per litre of premium-petrol in Euros;
- *IP*: the average of the two latter prices when information about the type of fuel used by the engine is not known;
- *KMP*: the kilometric price, or more precisely, the fuel operating cost per 100 kilometres. It is defined as $KMP_{ivt} = FE_{ivt} \times FP_{ivt}$, *FP* being the price of the type of fuel (*DP*, *IP*, or *IP*);

- *AD*: the age of the car if it is diesel-powered;
- *AP*: the age of the car if it is petrol-powered;
- *AI*: the age of the car if the type of fuel used is not known;
- *AN*: a dummy variable that states whether the age of the car is not known.

Additional variables that describe the characteristics of the household will also be used. They are detailed in the next subsection.

3.2 The econometric model

The annual mileage of a car *v* that is owned by household *i* at date *t* is modelled as:

$$\begin{aligned} KM_{ivt} = \sum_s \beta_{0s} \mathbf{1}(R_{it} = s) + \beta_1 KMP_{ivt} + \beta_2 AD_{ivt} \\ + \beta_3 AP_{ivt} + \beta_4 AI_{ivt} + \beta_5 AN_{ivt} + \varepsilon_{ivt}, \end{aligned} \tag{11}$$

The error term ε_{ivt} is assumed to be drawn from a zero-mean normal distribution. The model intercept β_0 is here differentiated according to the household residential location: either Paris city ($R_{it} = 1$), or the inner suburbs of Paris ($R_{it} = 2$), or the outer suburbs of Paris ($R_{it} = 3$), or the Provinces ($R_{it} = 4$). The automobility of a household *i* at date *t* is got by summing the mileages of the cars it owns at this date. Thus aggregated, the following model emerges:

$$\begin{aligned} KM_{it} = \sum_v KM_{ivt} = \sum_s \beta_{0s} \mathbf{1}(R_{it} = s) NC_{it} + \beta_1 \sum_v KMP_{ivt} + \beta_2 \sum_v AD_{ivt} \\ + \beta_3 \sum_v AP_{ivt} + \beta_4 \sum_v AI_{ivt} + \beta_5 \sum_v AN_{ivt} + \sum_v \varepsilon_{ivt}, \end{aligned} \tag{12}$$

where NC refers to the number of cars.

The previous specification is enlarged by introducing additional variables to allow for a better control of households heterogeneity: the household annual income in Euros, three dummy variables describing the age class of the household head ([18-39], [40-65], >65), the number of adults (except the head), the number of working adults, the number of women, the number of driving-license owners, and the number of children in the household.

Finally, according to the type of addiction model (myopic or rational) to be estimated, the specification also includes the past and future household automobility ($KM_{t\pm 1}$) as explanatory variables.

3.3 Selectivity, heteroskedasticity and endogeneity

The addiction models require that the dependant variable is not censored. The fact is that the survey from which we have drawn the data contains households that did not own cars. The annual mileage for these non-motorized households is zero, corresponding in microeconomics to a corner solution. The automobility models have been estimated using the subsample of households that declared to own at least one car in 2000. However, excluding the non-motorized households may result in a sample selection problem.

We have accounted for this likely selection bias by applying a two-step estimation procedure (Heckman, 1979). In a first step, we have estimated a dichotomous Probit model that explains household car ownership in 2000. We have then used the results to estimate the inverse Mills ratio λ, say $\hat{\lambda}$. The latter has in turn been used as an independent variable in the household mileage equation, which has been estimated using the subsample of car owner households in 2000. This corrects the potential bias by capturing the correlation between the ownership-based selection and the automobility models. Testing for selection bias is easily carried out by checking whether the estimated coefficient that weighs $\hat{\lambda}$, say $\beta_{\hat{\lambda}}$, is statistically different from zero.

This correction method of sample selection is not without some difficulties. Actually, the introduction of $\hat{\lambda}$ into the automobility model generates heteroskedasticity, as it makes the variance of the related error depend on the covariates used in the ownership Probit model (Heckman, 1979). Besides, the use in a specification of pre-estimated variables ($\hat{\lambda}$ in our case) as determinate covariates generally leads to underestimate the estimator variance[3]. In such circumstances, the correction provided in Murphy and Topel (1985) can be applied.

Sample selection is not the only reason why heteroskedasticity has to be taken into account. The structure of the proposed model is also a source. For instance, stating that the error terms ε_{ivt} are identically and independently distributed is not a convincing assumption. Indeed, a negative shock on the error of a household's car (as a breakdown) can induce a positive impact on the error of other household's cars. Typically, this is designing a correlation pattern of errors between the cars of a same household: $\text{cov}(\varepsilon_{ivt}, \varepsilon_{iv't}) \neq 0$. Besides, random shocks, caused by particular traffic conditions or public transport supply for example, can be unequally passed on to the car mileages of a household. They should also depend on the location and the ownership level: $\text{var}(\varepsilon_{ivt}) \neq \text{var}(\varepsilon_{i'v't})$ for $i \neq i'$ or $v \neq v'$. At last, the summation of car mileages to compute household automobility is also producing heteroskedasticity, related to the car ownership level. Therefore, an estimation method allowing for a complex form of heteroskedasticity must be applied.

By involving simultaneously both the lagged and the forwarded dependant variables as covariates, the dynamic specification of the rational addiction model makes them necessarily endogenous, even assuming the temporal independence of individual errors. Moreover, the errors are likely to be serially correlated due to an unobservable time invariant heterogeneity factor η_i, assuming that $\sum_v \varepsilon_{ivt} = \varepsilon_{it} = \eta_i + u_{it}$. Therefore, $KM_{it\pm1}$ and ε_{it} are correlated variables, and estimating the model by means of ordinary least squares would produce biased estimates.

3.4 Estimation strategy and tests

A solution resides in turning to estimators that use instrumental variables. Among those existing, the 2SLS estimator has almost but not all the desired properties. Although convergent, it is not consistent in the presence of heteroskedastic error terms. It may however be used to test for existence of heteroskedasticity (Breush and Pagan, 1979). If the test rejects

[3] If the variable $\hat{\lambda}$ proves statistically non-significant, the correction can be ignored. This point will be more discussed in section 5.2.

the homoskedasticity assumption, the Generalized Method of Moments (GMM) should then be applied. Proposed by Hansen (1982), this method generalizes other estimators such as the OLS and the 2SLS estimators. A condition of application of the GMM is however to use a set of "good" instruments. They need to be orthogonal to the estimation residuals and enough correlated with the endogenous variables to be instrumented. Both properties have therefore to be examined. To that extent, tests proposed by Hansen (1982) and Bound et al. (1995) are implemented. The readers are referred to Baum et al. (2003) for a detailed discussion.

4.0 Data and descriptive statistics

4.1 Data source

Data are drawn from the French "Car Fleet[4]" panel survey, which is achieved annually since 1984 by the private pooling institute TNS-Sofres[5]. The survey aspires to a better knowledge of several dimensions of the automobile demand, especially car ownership and use. It depicts with a great level of details many of the attributes of the cars owned by the households, as well as many of their characteristics. A nationally representative sample of 10 000 households is surveyed each year. The panel is rotating: about one third of the sample is renewed each year. Such a methodology allows for a longitudinal follow-up of some households for at least 3 years. In the present paper, we focus on households that were surveyed over the period 1999-2001.

4.2 Descriptive statistics

We have identified 3010 households continuously present in the waves 1999, 2000 and 2001 of the survey. On annual averages, slightly less than 20 per cent of them have no car, about 50 per cent have one car, slightly more than 25 per cent have two cars and about 5 per cent have three cars or more.

The average automobility of households is monotonically decreasing over the considered period, from 15 610 kilometres in 1999 down to 14 826 kilometres in 2001. Excluding households without a car to cancel out the decision related to car ownership, we observe the same decreasing trend: the average household mileage decreases also monotonically from 19 279 kilometres to 18 189 kilometres over the period. Table 1 reports the annual descriptive statistics about the characteristics of the sampled households.

[4] "Car Fleet" is the literal translation from French of the original name of the survey, "*Parc Auto*".
[5] Sofres is the acronym for "*Société Française d'Études par Sondages*".

TABLE 1: Descriptive statistics of household characteristics

Year	1999		2000		2001	
Variable	**Average**	**Std Dev.**	**Average**	**Std Dev.**	**Average**	**Std Dev.**
# cars	1.18	0.82	1.19	0.80	1.20	0.82
# adults	1.86	0.74	1.86	0.74	1.87	0.75
# employed adults	1.00	0.85	0.98	0.85	0.98	0.86
# women	0.98	0.48	0.98	0.48	0.98	0.48
# children	0.52	0.93	0.50	0.91	0.49	0.90
# licences	1.55	0.82	1.56	0.81	1.57	0.81
Annual income (10^3 EUR)	23.08	13.68	23.82	13.95	27.70	14.37
Age of the chief:						
<40	0.34	0.47	0.31	0.46	0.29	0.45
]40 ; 65]	0.42	0.49	0.42	0.49	0.42	0.49
>65	0.24	0.43	0.27	0.44	0.29	0.45
Residential location:						
Paris-city	0.05	0.22	0.05	0.22	0.05	0.22
Inner suburbs of Paris	0.06	0.24	0.06	0.24	0.06	0.24
Outer suburbs of Paris	0.07	0.25	0.07	0.25	0.07	0.25
The Provinces	0.82	0.38	0.82	0.38	0.82	0.38
Automobility (km) (motorized HHs only)	19279	12759	18563	12313	18189	12576
Automobility (km) (all HHs)	15610	13752	15193	13240	14826	13371

Source: 1999-2001 French Car Fleet panel (3010 households).

In 1999, a total of 3552 cars are reported by the households in the panel. It is a total of 3576 cars in 2000 and a total of 3605 cars in 2001. Based on this sample, Table 2 provides the descriptive statistics regarding car attributes and mileages. In 2000, the average car is almost 6.8 years old. According to the engine type, petrol-powered cars are about two years older on average than diesel-powered cars. This difference results from the very dynamic trend of global dieselization of the French car fleet (Hivert, 1999). In 1980, diesel cars represented less than 5 per cent of the total fleet in France. This share has continuously increased to reach about 15 per cent in 1990, 30 per cent in 1995, 35 per cent in 1999 and 40 per cent in 2001[6]. In accordance with these figures, the proportion of diesel cars is also increasing in our data, from 35 per cent in 1999 to 38 per cent in 2001. Dieselization explains partially the improvement in time of the average energy efficiency of vehicles, since diesel cars are less fuel-consuming than petrol cars of about 0.9 litres for 100 kilometres (Table 2). It also derives from the improvement of the fuel efficiency for both types of car over time: globally in the

[6] This phenomenon has even continued on the same pace during the 2000’s: this proportion was about 50% in 2005 and 55% in 2008.

data, the average vehicle consumed 7.33 litres of fuel for 100 kilometres in 2001 to 7.44 litres initially in 1999.

TABLE 2: Descriptive statistics of car characteristics

Year	**1999**		**2000**		**2001**	
	Average	**Std Dev.**	**Average**	**Std Dev.**	**Average**	**Std Dev.**
Repartition						
Diesel cars	0.34	0.23	0.36	0.23	0.38	0.24
Petrol cars	0.64	0.23	0.63	0.23	0.61	0.24
Mileage (km)						
Diesel cars	17786	9014	17085	9099	16187	8662
Petrol cars	11001	6564	10412	6138	10157	6172
Energy efficiency (L/(100 km))						
Diesel cars	6.82	1.29	6.80	1.49	6.74	1.35
Petrol cars	7.74	1.63	7.72	1.58	7.67	1.56
Age (in years)						
Diesel cars	5.19	4.01	5.52	4.28	5.48	4.38
Petrol cars	7.22	5.70	7.50	5.86	7.56	5.99
# observations	3552 cars		3576 cars		3605 cars	

Note: all the personal cars described by the households of the panel. Statistics for fuel-ambiguous cars (2% of the car sample for 1999, 1% for 2000 and 2001) not reported. Source: 1999-2001 French Car Fleet panel.

After a period of low fuel prices during the 1990's, the year 2000 marked an episode of significant raise: in 1999, due to the decision of various oil-producing countries (including OPEC) to limit the production, the price of crude oil barrel has increased. On annual averages, the price per litre of premium-petrol in France raised from EUR 0.98 in 1999 to EUR 1.14 in 2000 (from EUR 0.69 to EUR 0.85 for diesel-oil). But this increase has been short-lived, because during 2000, the production of oil has increased again, resulting in a decline of fuel prices for the following year: in 2001, the price for one litre of premium-petrol dropped to EUR 1.09 (EUR 0.80 for diesel-oil). However, the 1999-2001 whole result still represents an increase in price for both premium-petrol (+11%) and diesel-oil (+16%) (Table 3).

These differences in fuel price and energy efficiency partly explain the more intensive use of diesel cars. These ones have covered 17 085 km on average in 2000 to "only" 10 412 km for petrol cars. Between 1999 and 2001, the average mileages have decreased by 1600 km and 840 km for diesel and petrol cars respectively (Table 2). Thus, the decrease has been higher for diesel-powered cars than for petrol-powered cars. A reason is that the diesel-oil price per litre has increased faster than the petrol price.

TABLE 3: Evolution of the average fuel prices at filling stations in France (euros per litre)

Year	1999	2000	2001
Diesel-oil	0.6890	0.8461	0.7958
Premium-petrol	0.9825	1.1380	1.0877

Source: calculations from the yearbooks of the French professional comity of oils (*Comité Professionel Des Pétroles*).

5.0 Results

Table 4 reports the estimates of the selection model, which is the top layer of our modelling approach. It models the household probability to own at least one car in 2000. These estimates are then used to compute the correction factor $\hat{\lambda}$, which is introduced in the automobility model to control for selection.

TABLE 4: Selection model estimates

Variables	coefficient	t-stat
Annual income (10^3 EUR)	1.42	4.91
Age of the HH chief (reference: [40 ; 65[)		
[18 ; 40[	−0.10	−0.80
≥ 65	0.22	2.19
HH location (reference: Paris city)		
Inner suburbs of Paris	0.68	3.81
Outer suburbs of Paris	1.64	8.10
The Provinces	1.65	11.13
# driving licence owners	1.50	20.22
# adults (except the head)	0.07	0.91
# employed persons	0.11	1.43
# women	−0.36	−4.05
# children	0.15	2.44
Intercept	−2.63	−12.99

Note: estimation for wave 2000 of the panel, 3010 households. Dependant variable: $Y_i = 1$ if the household owned at least one car (2631 cases), 0 otherwise (379 cases). Probit estimation.

The estimates of the addiction models are reported in Table 5.

TABLE 5: Estimates of the myopic and rational addiction models for household automobility

Variable	Myopic addiction model		Rational addiction model	
Past automobility (KM_{t-1})	0.307	(3.41)	0.346	(4.20)
Future automobility (KM_{t+1})	-		0.295	(3.98)
(Cumulated) kilometric price $(\sum_v KMP_v)$	−362.68	(−3.04)	−223.29	(−1.98)
HH's annual income	87.37	(3.98)	46.37	(2.16)
# cars (NC) **for HH living in:**				
Paris-city $(R{=}1)$	8813.36	(4.45)	5514.74	(2.94)
the inner suburbs of Paris $(R{=}2)$	8540.45	(4.46)	4888.76	(2.63)
the outer suburbs of Paris $(R{=}3)$	10810.79	(5.50)	6310.44	(3.08)
the Provinces $(R{=}4)$	11038.71	(5.56)	6189.06	(2.96)
(Cumulated) age of cars:				
diesel $(\sum_v AD_v)$	−24.75	(−0.34)	−12.39	(−0.18)
petrol $(\sum_v AP_v)$	−191.68	(–4.04)	−104.05	(−2.28)
imprecise $(\sum_v AI_v)$	–57.04	(−0.46)	–30.26	(–0.28)
age not given $(\sum_v AN_v)$	−2439.82	(−3.20)	–1112.06	(–1.53)
# driving licence owners	2138.45	(3.13)	1324.65	(2.16)
# adults (except the HH chief)	510.27	(1.01)	409.90	(0.96)
# employed persons	815.36	(2.07)	286.32	(0.76)
# women	–2041.94	(–3.34)	–1158.26	(–2.16)
# children	–174.637	(–0.61)	–297.28	(–1.16)
Age of HH chief (ref : [18-40[)				
[40-65[	–1617.14	(–2.64)	−1376.77	(–2.51)
≥ 65	–2648.16	(–3.68)	−1608.01	(−2.34)
Selection correction factor $(\hat{\lambda})$	2430.34	(1.71)	1555.84	(1.26)
Intercept	–1210.78	(–0.90)	–954.01	(–0.85)
ρ	∞		17.04%	
R^2	0.87		0.90	
Fisher (p-value)	F(19, 2611): 82.6 (0.00)		F(20, 2610): 115.5 (0.00)	
Breush-Pagan (p-value)	$\mathcal{X}^2$ (40): 777.0 (0.00)		$\mathcal{X}^2$ (40): 878.8 (0.00)	
Hansen (p-value)	$\mathcal{X}^2$ (21): 30.46 (0.08)		$\mathcal{X}^2$ (20): 23.22 (0.28)	
Bound (p-value)	F(22, 2590) KMt-1: 3.80 (0.00)		F(22, 2590) KMt-1: 3.80 (0.00) KMt+1: 4.51 (0.00)	

Note: subsample of 2631 households which described at least one car in 2000. Denominations of variables are in section 3.0. Dependant variable: *KM* in 2000. GMM estimation with 11 excluded instruments for 1999, 11 for 2001, 18 current instruments included in the specification. T-statistics in parentheses. The Breush-Pagan statistic is computed from the residuals of models estimated by 2SLS.

5.1 Fit properties

Both myopic and rational addiction models present good fit properties. The R^2 statistics are respectively 0.87 and 0.90, and the Fisher statistics show that the set of explanatory variables is relevant to explain the dynamics of household automobility. The Breush-Pagan statistic after estimating the models by 2SLS rejects the homoskedasticity assumption, and justifies resorting to the GMM estimator as IV technique.

The instruments that were used to implement the GMM are the set of current exogenous covariates (“included” instruments) and a set of past and future household characteristics (“excluded” instruments). In both models, the Hansen test concludes to acceptance of the null hypothesis of orthogonality between residuals and instruments. Besides, the Bound test accepts the alternative hypothesis of joint significance of the excluded instruments to explain the endogenous covariates.

5.2 Selectivity

Both models agree not to accept the significance hypothesis of the correction term $\hat{\lambda}$. Formally, the null hypothesis $\mathrm{H0}: \beta_{\hat{\lambda}} = 0$ cannot be rejected at the 5 per cent level, meaning that the selection of car owner households in 2000 to estimate the automobility models has not been a source of bias. Under H0, the estimator variance corrected according to the Murphy-Topel method amounts to the variance without correction[7]. Thus, the uncorrected estimator variance should not differ statistically from the corrected variance. Moreover, whichever the addiction model, the Hausman test leads to accept the null hypothesis of equal estimates between the unconstrained model and the model constrained by $\beta_{\hat{\lambda}} = 0$. Therefore, using the unconstrained estimates and the uncorrected estimator variance (from Table 5) for inferential purposes is legitimate.

5.3 Addiction and inter-temporal rate of substitution

While the results substantiate the addictive behaviour regarding automobility, the rational addiction model emerges as the most relevant to describe the sort of car dependence of households captured by the data. Indeed, the myopic model confirms the significant effect of the past annual mileage on current automobility. But on the other hand, the rational model rejects behavioural myopia as the parameter that weighs the forwarded annual mileage is also statistically significant. Therefore, households are forward-looking agents in setting their current automobility. Furthermore, the rational addiction model yields an inter-temporal rate of substitution of about 17 per cent, which is a rather plausible value.

5.4 Price and income elasticities of automobility

The estimates related to the kilometric price have the expected negative signs in both models, but their levels of significance slightly differ. It is significant at the 1 per cent level in the myopic model while it is just significant at the 5 per cent level in the rational model.

Elasticity measures of household automobility to the kilometric price are reported in Table 6. The myopic and rational addiction models agree to measure a short-run price-elasticity of

[7] Referring to the correction formula in Greene (2003, p.510), the corrected estimator variance (V_2^*) is equal to the uncorrected variance ($n^{-1}V_2$) as in our case, C drop to zero under $\mathrm{H0}: \beta_{\hat{\lambda}} = 0$.

−0.22. Because of a larger inter-temporal dimension in the rational addiction model, the long-run price-elasticity is higher (−0.37) than in the myopic model (−0.31). In level, a permanent raise of EUR 1 of the cost to achieve 100 km causes a decrease in the annual mileage per car of 380 km in the short run, and 623 km in the long run (Table 7).

TABLE 6: Short and long-run elasticities of household automobility with respect to kilometric price and income

	Kilometric price		Income	
Addiction model	**Myopic**	**Rational**	**Myopic**	**Rational**
Short-run	−0.22 [−0.34;−0.10]	−0.23 [−0.41;–0.05]	0.11 [0.06 ; 0.16]	0.10 [0.03 ; 0.16]
Long-run	−0.31 [−0.47;−0.16]	−0.37 [−0.72;−0.08]	0.16 [0.09 ; 0.23]	0.16 [0.06 ; 0.29]

Note: 95% confidence intervals in brackets.

TABLE 7: Short and long-run marginal effects on household automobility (km)

Horizon	**Short-run**	**Long-run**
Effect on HH automobility induced by:		
a EUR 1000 raise in the HH annual income	+79 [+20;+125]	+131 [+39;+859]
a EUR 1 raise in the price for 100 km of fuel, per car	−380 [−676;−79]	−623 [−1194;−138]

Note: evaluation from the rational addiction model (Table 5). 95% confidence intervals in brackets.

Estimating price-sensitivities of car use has been the topic of many works. To cite a few, such figures were estimated and discussed in Hensher et al. (1990), Oum et al. (1992), Eltony (1993), Rouwendal (1996), Johansson and Schipper (1997), Berri et al. (2005). Graham and Glaister (2002) collected many existing results in the literature dealing with car use sensitivities to fuel price, which can be expected to be close to our kilometric price-elasticities. In their study, Goodwin (1992) is a referenced paper: based on four elasticities drawn from empirical works in the 1980's, the author reported an average fuel price sensitivity of automobile traffic of −0.16 for the short run, and −0.33 for the long run. Goodwin et al. (2004) updated this result with empirical works published in the 1990's and in the early 2000's. The authors reported an average sensitivity of mileage with respect to fuel price of −0.10 for the short-term and −0.30 for the long-term.

In our present application, the most relevant model to be compared with the literature is probably the myopic addiction model, since short and long-run elasticities are usually derived from first-order autoregressive specifications. In this model, the long-run kilometric price elasticity of household automobility, estimated at −0.31, emerges as a very plausible value.

Relatively, the short-run elasticity obtained from this model (−0.22) might seem high, meaning a fast rate of convergence to the long-term equilibrium. In other words, French households adapt quickly their automobility to a change in the kilometric price. This conclusion can also be drawn from Graham and Glaister (2002, p.22, fig.1). Indeed, these authors reported the price-elasticities of the demand for gasoline for a set of occidental countries: comparatively, France has one of the highest sensitivities in the short run and one of the lowest for the long run. The short-long ratio is about 3/4, while it is clearly below 0.5 for the other comparable countries (Germany, United Kingdom, Austria and Canada).
Table 8 reports the sensitivity of car annual mileage to fuel price by type of car. The elasticity of mileage for petrol-powered cars with respect to premium-petrol price is estimated at −0.32 in the short run and at −0.52 in the long run. Regarding diesel-powered cars, these elasticities with respect to diesel-oil price are respectively −0.13 and −0.21[8]. Thus, the use of petrol cars is about 2.5 times more sensitive to fuel price variations than diesel cars, both in the short and the long runs.

TABLE 8: Elasticities of annual mileage of cars with respect to fuel prices

Horizon	**Car type (fuel used)**	**Elasticity**
Short-run	**Diesel car (diesel-oil)**	−0.13 [−0.19;−0.10]
	Petrol car (premium-petrol)	−0.32 [−0.46;−0.25]
Long-run	**Diesel car (diesel-oil)**	−0.21 [−0.40;−0.14]
	Petrol car (premium-petrol)	−0.52 [−1.03;−0.36]

Note: elasticities evaluated at the average cars in 2000, using the estimates of the rational addiction model and the price for fuels in 2000 (see footnote 8). 95% confidence intervals in brackets.

The estimated coefficient that pertains to households' annual income is significant and has the expected positive sign in both models. Table 6 reports also the short and long-run elasticities of household automobility with respect to income. Whatever is the considered addiction model, these elasticities take similar values: about +0.10 in the short run and about +0.16 in the long run. Thus, an increase in household income entails a proportionally lower increase in automobility: in the economic sense, the kilometer proves to be a normal good. Using the results from the rational addiction model, a permanent increase by EUR 1000 in household

[8] Example: in 2000, the average fuel consumption for a diesel car was 6.80 litres of diesel-oil for 100 km, the average mileage for this type of car was 17 085 km (Table 2), and the price for one liter of diesel-oil was EUR 0.8461 (Table 3). Moreover, the long-run marginal effect of the kilometric price on automobility is estimated at −623 km by car (Table 7). For diesel cars, the long-run elasticity of mileage to the diesel-oil price is valuated at: $(-623\times6.80)\times(0.8461/17085)=-0.21$.

annual income yields an increase in automobility of about 79 km in the short run, and 131 km in the long run (Table 7).

As income is a key factor of household car ownership, income-elasticities of automobility should vary widely depending on whether the level of car equipment is held constant (as here) or not. In Hensher et al. (1990), the income-elasticities of car use for households living in the Sydney urban area ranged from +0.05 to +0.14 according to the level of car ownership of households. Cited for comparison in their study, Greene and Hu (1985) and Mannering and Winston (1985) respectively estimated this elasticity at +0.13 and +0.11 for the United States. Therefore, our results (Table 6) do not differ much from those got by these authors.

6.0 Conclusions

This article focuses on modelling the annual mileage covered by households with their personal cars, that is, their "automobility". It sheds new light on the car dependence issue. The results that are presented put an emphasis on the rational addiction model of Becker et al. (1994), which had not been applied on automobile data so far. Original in our context, this model lives up to expectations, when applied to describe the empirical automobility behaviour of French households in 2000. Indeed, the assumption of addiction to car use is not statistically rejected. Therefore, the assertions made in Dupuy (1999) and Wickham et al. (2002) (mentioned in the introduction) are reinforced by the microeconomic point of view. Then, the rational version of the addiction model proves to be more relevant than the myopic version. Indeed, both past and future household automobility are significant to explain the current automobility in the rational addiction model. Moreover, the inter-temporal rate of substitution is valuated at 17 per cent, which is a plausible value. Such results show that the household behaviour is consistent with a theoretical inter-temporal optimization scheme. This conclusion stands our work apart from earlier dynamic studies, which may have missed an important point in explaining car use demand. Indeed, models based on a first-order autoregressive specification are useful to derive short and long-run elasticities, but they also require the individuals to be myopic as it regards the future. Nonetheless, the myopic model is also reported for comparison with other studies.

In France, the kilometric-price and income elasticities of household automobility derived from the rational addiction model are in accordance with expectations. The respective estimations are −0.23 and +0.10 for the short run, −0.37 and +0.16 for the long run. These figures do not diverge from existing results that were reported in the literature. According to the type, petrol cars are more sensible than diesel cars to a change in fuel price. For diesel cars, the elasticity of annual mileage with respect to diesel-oil price is estimated at −0.13 at short run, while that for petrol cars with respect to premium-petrol price is measured at −0.32. The long-run elasticities are about 1.6 times higher. Our results are sensible whatever they are computed on the basis of the myopic addiction model or the rational addiction model. As it regards the latter approach, it strengthens our recommendation to use it when data are available.

There are several ways to improve our approach. First, it would be interesting to demonstrate the model using disaggregated data over a longer period of time. Second, it is assumed in the rational addiction model that the future level of automobility is known by the agents, although there is some kind of uncertainty about future. It would therefore be relevant to test for different specifications that pertain to expectations about future. Also, it would be interesting to compare our study with any other approach that incorporates the fact that decision-makers could be forward-looking agents.

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